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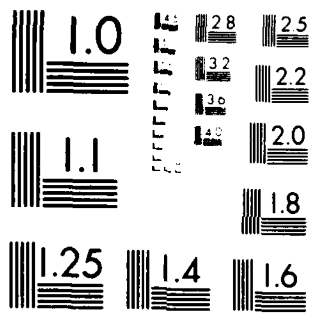

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AD-A136 146

TROPICAL CYCLONE WIND PROBABILITY FORECASTING FOR THE SOUTHERN HEMISPHERE (WINDPSH)

Prepared By:

Jerry D. Jarrell
Science Applications, Inc.
Monterey, CA 93940

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The development of a model to estimate 30 and 50 kt wind probabilities from Southern Hemisphere tropical cyclone forecasts is described. The model is based on position forecast errors, which are used to determine the probability of a tropical cyclone occupying a particular geographical position, and on wind profile errors. Wind profile errors consist of errors in the forecast maximum wind and errors in the forecast radius of 30 kt and 50 kt winds. The profile errors are used to estimate the probability of 30 and 50 kt winds occurring at

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Block 20, Abstract, continued.

a point, given that the tropical cyclone occupies a particular position. These position and wind probability elements are combined by using an assumption of independence which was supported by correlation coefficients in an earlier work.

The model, which includes features of earlier strike and wind probability models, is tested on independent data. Test results show good agreement between forecast probability and the frequency of 30 and 50 kt winds.

CONTENTS

TROPICAL CYCLONE WIND PROBABILITY FORECASTING FOR THE SOUTHERN HEMISPHERE (WINDPSH)

1.0 Introduction

The concepts and development of tropical cyclone wind probability forecasting for the Southern Hemisphere follow closely those originally presented by Jarrell[1] (1981) for the western North Pacific. This is the fifth in a series of wind probability forecasting program reports covering different ocean basin areas. The initial report on the western North Pacific was followed by similar reports on the western North Atlantic, eastern North Pacific and North Indian Ocean. This and the previous reports are based upon an extension of the concepts developed for tropical cyclone strike probability forecasting (Jarrell[2], 1978). As these concepts have been previously presented and the programs are presently operational, a redevelopment of the concepts will not be presented in this report. A brief summary will be presented as a background for the new reader.

Differences between the development of Southern Hemisphere tropical cyclone wind probabilities and that of its closest previous counterpart, the model for the Atlantic Ocean is the crux of this report and these will be described in detail.

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[1]Jarrell, J.D., 1981: Tropical Cyclone Wind Probability Forecasting (WINDP), NAVENVPREDRSCHFAC Contractor Report CR 81-03.

[2]Jarrell, J.D., 1978: Tropical Cyclone Strike Probability Forecasting, NAVENVPREDRSCHFAC Contractor Report CR 78-01.

The tropical cyclone wind probability forecasting model generates estimates of the probability of 30 and 50 knot winds occurring at a point. The model includes many features of the strike probability model, which is based on an analysis of position forecast errors to determine the probability of a tropical cyclone occupying a particular geographic position. Wind profile errors based on the forecast of maximum wind and the forecast radius of 30 and 50 knot winds are similarly analyzed to determine the 30 and 50 knot probabilities of occurrence.

Jarrell[2] (1978), in the development of the strike probability model, based the theory of strike probability on three assumptions:

1) All tropical cyclone forecasts are subject to error;
2) Difficulty of the forecast and size of the forecast error are statistically related; and
3) The occurrence of errors is random and approximates a multimodal bivariate normal probability distribution.

Studies by independent investigators in three ocean basins frequented by tropical cyclones verified these assumptions. Nicklin[3] (1977), Thompson et al[4] (1981), and

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[3]Nicklin, D.S., 1977: A Statistical Analysis of Western Pacific Tropical Cyclone Forecast Errors, Naval Postgraduate School, M.S. Thesis, June.

[4]Thompson, W.J., R.L. Elsberry and R.G. Read, 1981: An Analysis of Eastern North Pacific Tropical Cyclone Forecast Errors, Monthly Weather Review, V. 109, pp. 1930-1938.

Crutcher et al[5] (1982) using data from the western Pacific, eastern Pacific and the Atlantic, respectively, also developed individual methods to group forecasts into three classes of forecast difficulty. A general relative classification evolved in each study to yield forecast error groups of below average, average, and above average errors. These groups were also referred to as Class I (easy forecasts), Class II (average forecasts) and Class III (difficult forecasts) in previous reports. Each investigator also utilized sufficient statistical data and prescribed sufficient parameters to describe the bivariate normal distributions for each of the three classes and for forecasts of 24, 48, and 72 hours.

Following the work of Crutcher et al[5], southern hemisphere forecast errors were separated into groups using the NORMIX clustering model. The data set consisted of 789 forecasts issued by the Joint Typhoon Warning Center (JTWC) during the years 1976-1981. Unlike the other basins, only two significantly different clusters were identified. These two clusters are shown by 50% probability ellipses in Figure 1.

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[5]Crutcher, H.L., C.J. Neumann and J.M. Pelissier, 1982: Tropical Storm Forecast Errors and the Multimodal Bivariate Normal Distribution, J. Appl. Meteor., V. 21, pp. 978-987.

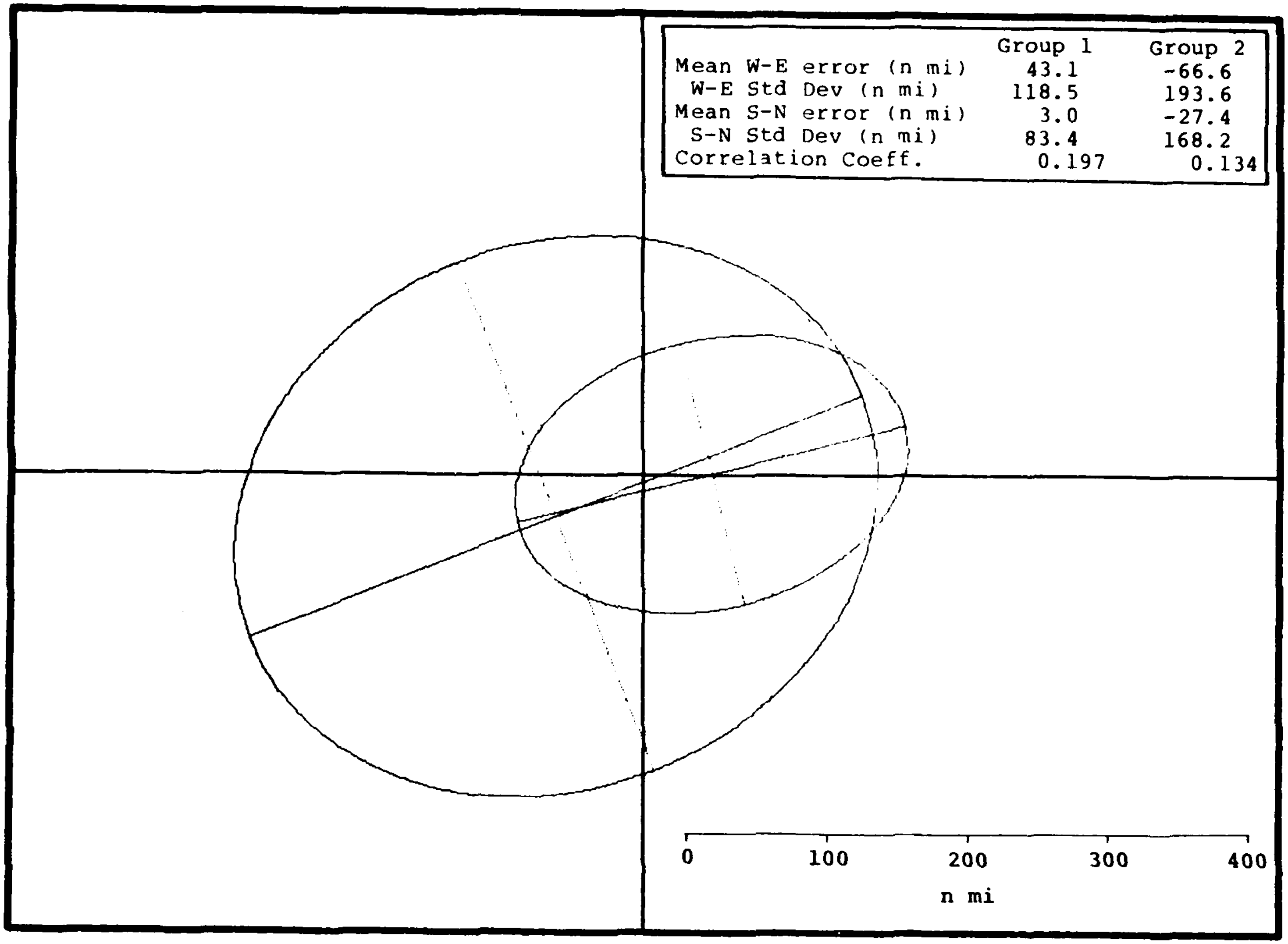

Figure 1. Fifty percent error probability ellipses for two clusters of 24-hr forecast errors identified by the NORMIX clustering model in the Southern Hemisphere. Distances are actual position - forecast position in nautical miles (n mi). The small and large ellipses represent forecast classes referred to as Groups 1 and 2 respectively.

2.0 Model Description

2.1 The Southern Ocean Model

One version of the tropical cyclone wind probability model was developed for the Atlantic Ocean as a modification to the western Pacific wind probability program. The concepts of the strike portion of the Southern Ocean model are similar to those developed for the Atlantic. The Southern Ocean model uses a regression equation to estimate the probability of a forecast belonging to either of two forecast classes (associated with two forecast error clusters) and the Tsui, et al, model[6] (used in the Atlantic wind probability model) to determine wind profiles and to handle asymmetrical wind distribution. Thus this model uses modified versions of both the wind probability and strike probability concepts used in the Atlantic.

The wind profiles and derived tropical cyclone asymmetry used in the Atlantic model were actually based on western Pacific data using methods produced by Tsui, et al, as indicated above. Tsui, et al, using wind radius data from tropical cyclone warnings over a 12-year period (1966 to 1977), determined that the profile of the tangential wind speed along the radial axis was exponential as a good approximation. He further determined that the size of the storm could be statistically related to the maximum wind and that the asymmetric shape of the storm's wind pattern was correlated to the forward speed of movement of the storm.

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[6]Tsui, T.L., L.R. Brody and S. Brand, 1982: A Technique for Predicting Surface Wind Distributions of Tropical Cyclones in the Western North Pacific, NAVENVPREDRSCHFAC Technical Report TR 82-05.

A simple empirical relationship was derived to provide an estimation of wind at any radius.

$$V/V_{max} = \exp(-0.693R),$$

where V is the wind speed of interest, V_{max} is the maximum wind speed of the storm, and R is the ratio of the radius associated with V to the radius associated with one- half of V_{max} (r_{half}). Radii are measured outward from the radius of maximum winds. Asymmetrical storm configuration is accommodated in the profile by an empirical adjustment of the one-half radius, r_{half}, dependent on bearing relative to direction of motion and translation speed. With due regard to the sparsity of data available in the southern hemisphere, 30 and 50 kt wind radii forecasts were treated as being without skill. Accordingly rather than predicting r_{half} as a function of these radii, a relationship based on Atlantic data was used relating r_{half} to maximum wind. While the Tsui model is considered entirely appropriate for this area, the Atlantic relationship may be somewhat suspect since Atlantic storms occur at more poleward latitudes and, all other things being equal, may be slightly larger than Southern Hemisphere counterparts. If true this would cause a slight over forecast of wind probabilities.

3.0 Testing the Southern Hemisphere Wind Probability Program (WINDPSH)

The methodology used in comparing WINDPSH predicted values against observed values is identical to that used in the North Indian Ocean. An array of 30 points in the Southern Hemisphere were selected (Figure 2). WINDPSH values for 30 and 50 knots were calculated at 12 hour intervals from the effective synoptic time of the Joint Typhoon Warning Center (JTWC) forecasts for the twenty 1982 season cyclones. Since most of these 30 points are not observing stations, actual verifying winds were not generally available. Consequently a verifying "warning time" probability of 50 or 30 winds greater than 50% constituted a verifying observation over 50 or 30 kt winds.

Tables 1 and 2 compare the expected to the observed occurrences of 30 and 50 knot winds. The test cases were 217 forecasts (12 hr intervals) on twenty 1982 cyclones. Of the 217 forecasts there were 129 and 88 verifiable at 24 and 48 hours respectively. Predictions are associated with percentage groups of increasing width, <1/2%, 1/2 to 1 1/2%, ..., etc. Time integrated probabilities were verified only if a continuous record was available over the entire time period. Significance of the differences between the expected and the observed, as discussed in previous reports (Jarrell[7], 1981) is difficult to assess, but using a "t" test, agreement is excellent. The difference between the expected and observed occurrences was significant (5%) in only two of 72 comparisons and, although the sample is small, the overall results are considered statistically very sound.

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[7]Jarrell, J.D., 1981: Atlantic Strike Probability Program, NAVENVPREDRSCHFAC Contractor Report CR 81-04.

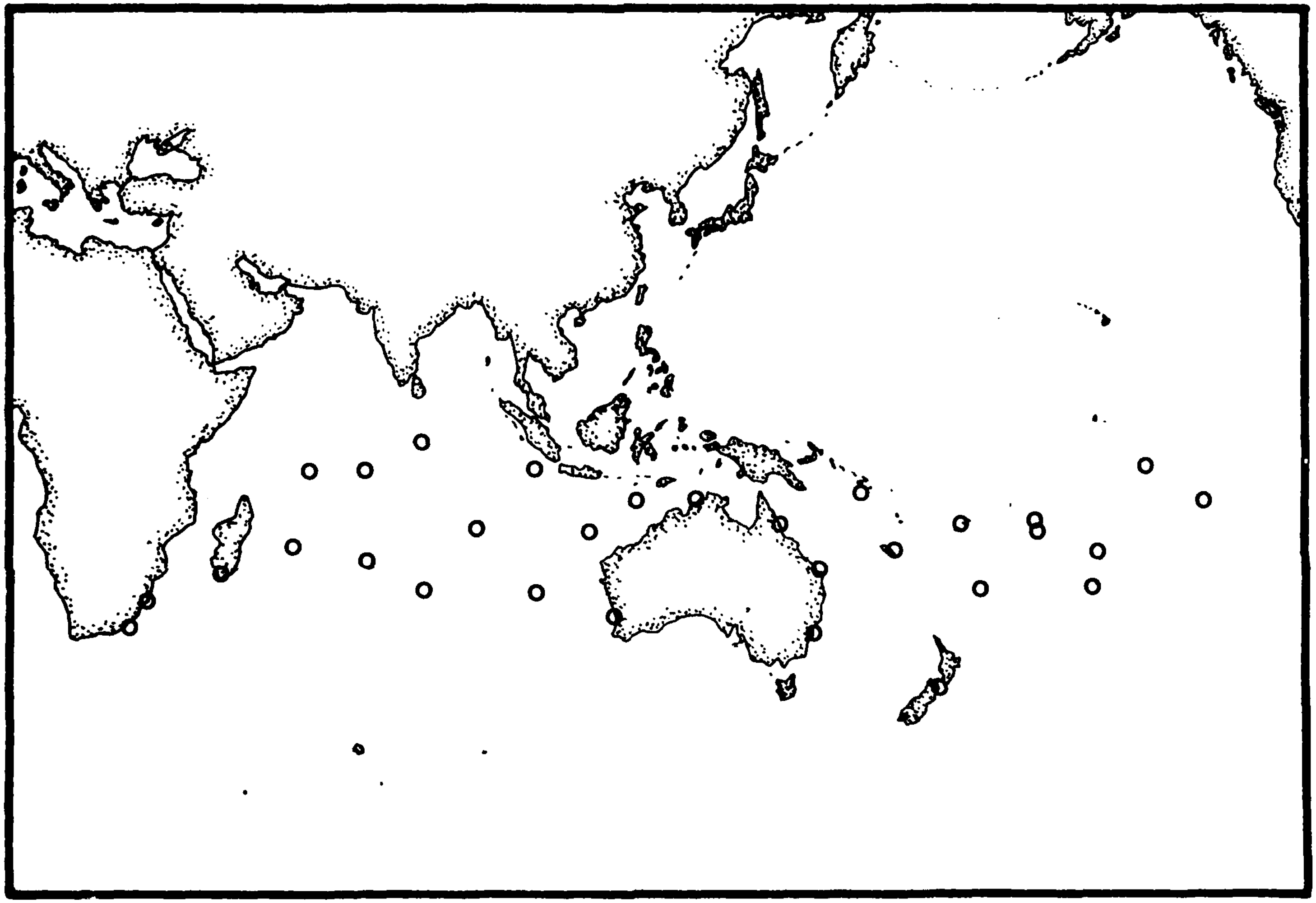

Figure 2. Selected test points (30) in the Southern Hemisphere.

Table 1. Comparisons of expected occurrence (E) to observed occurrences (O) of 50 kt (a) and 30 kt (b) winds in a test sample of 3870 verifiable instantaneous wind probability computations.

a) 50 kt instantaneous wind probabilities

	24 HR			48 HR		
$A \leq P < B$	N	E	O	N	E	O
< 1/2%	3768	0	0	2446	0	0
1/2 - 1 1/2	36	0	0	96	1	0
1 1/2 - 3 1/2	33	1	0	47	1	1
3 1/2 - 7 1/2	18	1	1	48	2	3
7 1/2 - 15 1/2	9	1	1	3	0	0
15 1/2 - 31 1/2	6	1	2	0	0	0
31 1/2 - 63 1/2	0	0	0	0	0	0
> 63 1/2	0	0	0	0	0	0
ALL	3870	4	4	2640	4	4

b) 30 kt instantaneous wind probabilities

	24 HR			48 HR		
$A \leq P < B$	N	E	O	N	E	O
< 1/2%	3636	0	0	2329	0	0
1/2 - 1 1/2	69	1	0	93	1	0
1 1/2 - 3 1/2	37	1	1	64	2	1
3 1/2 - 7 1/2	37	2	2	63	3	1
7 1/2 - 15 1/2	37	4	3	54	6	8
15 1/2 - 31 1/2	30	7	6	37	7	11
31 1/2 - 63 1/2	24	13	11	0	0	0
> 63 1/2	0	0	0	0	0	0
ALL	3870	28	23	2640	19	21

Table 2. Comparisons of expected occurrence (E) to observed occurrences (O) of 50 kt (a) and 30 kt (b) winds in a test sample of 3840 time integrated wind probabilities.

a) 50 kt instantaneous wind probabilities

	24 HR			48 HR		
$A \leq P < B$	N	E	O	N	E	O
< 1/2%	3691	0	0	2319	0	0
1/2 - 1 1/2	48	0	0	73	1	0
1 1/2 - 3 1/2	22	1	0	61	1	0
3 1/2 - 7 1/2	30	2	0	41	2	0
7 1/2 - 15 1/2	20	2	1	43	5	1
15 1/2 - 31 1/2	22	5	3	35	7	5
31 1/2 - 63 1/2	6	3	3	7	3	3
> 63 1/2	1	1	1	1	1	1
ALL	3840	14	8	2580	20	10

b) 30 kt instantaneous wind probabilities

	24 HR			48 HR		
$A \leq P < B$	N	E	O	N	E	O
< 1/2%	3523	0	0	2204	0	0
1/2 - 1 1/2	71	1	0	71	1	0
1 1/2 - 3 1/2	57	1	0	65	2	0
3 1/2 - 7 1/2	37	2	1	61	3	1
7 1/2 - 15 1/2	42	5	2	66	7	2
15 1/2 - 31 1/2	56	12	8	65	14	11
31 1/2 - 63 1/2	33	15	16	31	14	17
> 63 1/2	21	17	16	17	13	13
ALL	3840	53	43	2580	54	44

4.0 Operational Products

The Southern Ocean wind probability program will be available for nine preselected points.* Probabilities will be given in two modes, instantaneous and time integrated, and at 0, 12, 24, 36 and 48 hours after the warning time. The instantaneous probability will be the probability at the stated time (i.e., 12 hr) and the time integrated probability will be summed from time 0 to the stated time for an estimate of the probability that the event will be observed within that period of time.

The greatest source of error for the WINDPSH program will be erroneous input data. An internal check for unusual motion (expected to occur only 5% of the time in nature) will be made and suspect motion flagged. The user should then recheck input data for accuracy.

When the forecast track approaches a land mass, the forecaster should be aware of program bias. This should be minor for seaward aproach to low coastal areas or over smaller islands. However, in other cases, land influences will appear as rapid decreases in the instantaneous wind probabilities (especially 50 kt winds) near forecast landfall time. This will bias probabilities - overstate them for inland sites and understate them for coastal sites. Time integrated probabilities will be less biased. This problem is caused by wind forecasts being influenced by track forecasts where landfall is concerned. A bad track forecast

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*Locations: Brisbane, Sydney, Auckland, Darwin, Perth, H.E. Holt, Learmonth, Fremantle and Diego Garcia.

may cause a bad wind forecast. This was not accounted for either in development or testing; hence the test results simulate expected actual operational results and some of the minor disparities between expected and observed occurrences no doubt stem from this.

Figure 3 depicts a standard output of WINDPSH for Cyclone Arthur, 14 January 1981. Probabilities are provided at 12 hour intervals for strike, 50 and 30 kt winds in both instantaneous and time integrated modes. The format is HHPIPS where HH is hours after forecast effective time, PI and PS are the instantaneous and time integrated probability rounded to the nearest whole percent. The letters "IN" mean less than one half percent while "THREAT NIL" means all probabilities were less than one half percent.

The other message that WINDPSH will generate is created for the Office of Foreign Disaster Assistance (OFDA), Agency for International Development. This message will be triggered when any of approximately 130 cities worldwide is threatened by a tropical cyclone. Of these cities 26 are in the Southern Hemisphere.

The message will state the storm's name and intensity category, which ocean the storm is in, the latitude and longitude of the storm, the center wind speed in knots, and estimates of the threat of hurricane force winds. The estimates are:

```
WINDP1        MESCON8090

  STRIKE AND WIND PROBABILITY FORECAST

  ARTHUR        141900Z

  BRISBANE      THREAT NIL

  SYDNEY        THREAT NIL

  AUCKLAND      00ININ 12ININ 24ININ 36ININ 48ININ

     50 KNOT    00ININ 12ININ 24ININ 36ININ 48ININ

     30 KNOT    00ININ 12ININ 24ININ 36ININ 480102

  DARWIN        THREAT NIL

  PERTH         THREAT NIL

  H E HOLT      THREAT NIL

  LEARMONTH     THREAT NIL

  DIEGO GARC    THREAT NIL

  FOR METEOROLOGISTS:  FORECAST CONFIDENCE TABLE

         TIME  PROB  DIST  PROB  DIST  PROB

         12HR   22    50    20    75    58

         24HR   28   100    23   150    49

         48HR   26   200    22   300    52


  PROBABILITIES BASED ON FOLLOWING FORECAST

  001951787055 122131798045 242281785045 48260170040
```

Figure 3. Standard WINDPSH output, listing probabilities of a strike and 30 and 50 kt winds at Auckland for Cyclone Arthur, 14 January 1981. Forecast confidence table gives the probability of actual verification within 50 n mi, 50-75 n mi and outside 75 n mi for the 12 hour forecast and comparable values for radii twice as large for 24 hours and four times as large for 48 hours.

Danger	(Red) if the probability of 65 kt winds or greater (P65) exceeds 20% within 18 hours, otherwise
Alert	(Orange) if P65 exceeds 10% within 24 hours, otherwise
Caution	(Yellow) if P65 exceeds 5% within 48 hours, otherwise
Notice	(Green) if P65 exceeds 2 1/2% within 48 hours.

Figure 4 shows an example of the OFDA message.

```
A.  FOR OFFICIAL USE ONLY
B.  TROP STORM ARTHUR JAN 14, 1981 1900 GMT LOCATED IN S.
    PACIFIC OCEAN AT 19.5S 178.7E WITH CENTER WINDS OF 55 KTS.
    ESTIMATES OF THREAT OF HURRICANE FORCE WINDS FOLLOW:
    (REFER TO USERS MANUAL NAVENVPREDRSCHFAC DOCUMENT
    UM-06 8/82)
         OFDA SELECTED POINTS           THREAT LEVEL
         NANDI  FIGI                    CAUTION (YELLOW)
         SUVA  FIGI                     ALERT (ORANGE)
         NUKUALOFA TONGA IS.            NOTICE (GREEN)
C.  THREAT TO ALL OTHER OFDA POINTS BELOW NOTICE (GREEN)
    THRESHOLD FROM THIS STORM
D.  RECOMMEND READDRESS AS FOLLOWS:
         NIACT:
           SUVA
         IMMEDIATE:
           NONE

(Note: NIACT is a State Department Message handling
Precedence .. Night Action)
```

Figure 4. OFDA message of threat estimates for cities near the path of Cyclone Arthur, 14 January 1981.

5.0 Summary

The wind probability model for the southern oceans is largely based on the wind probability program for the North Atlantic. Some features of wind probability programs for the eastern and western North Pacific and the North Indian oceans have also been incorporated. All of these programs are now operational. Test results for the Southern Hemisphere wind probability program (WINDPSH) demonstrated excellent agreement between expected and observed results. Operational products are available both in message form as described herein and through the Naval Environmental Display Station (NEDS) as plotted charts.

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NEWPORT, RI 02840

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NAVAIRSYSCOM (AIR-330)
WASHINGTON, DC 20361

COMMANDER
AWS/DN
SCOTT AFB, IL 62225

USAFETAC/TS
SCOTT AFB, IL 62225

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DEFENSE TECH. INFORMATION
CENTER, CAMERON STATION
ALEXANDRIA, VA 22314

DIRECTOR
OFFICE OF ENV. & LIFE SCI.
OFFICE OF THE UNDERSEC OF
DEFENSE FOR RSCH & ENG, E&LS
RM 3D129, THE PENTAGON
WASHINGTON, DC 20505

FEDERAL COORD. FOR METEORO.
SERVS. & SUP. RSCH. (OFCM)
11426 ROCKVILLE PIKE
SUITE 300
ROCKVILLE, MD 20852
ROCKVILLE, MD 20852

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NOAA, GABLES ONE TOWER
1320 S. DIXIE HWY
CORAL GABLES, FL 33146

DIRECTOR
INTERNATIONAL AFFAIRS OFFICE
NOAA (OAX4)
6010 EXECUTIVE BLVD.
ROCKVILLE, MD 20852

DIRECTOR (AOML)
NATIONAL HURRICANE RSCH. LAB.
1320 S. DIXIE HWY.
CORAL GABLES, FL 33146

THE EXECUTIVE DIRECTOR
AMERICAN METEORO. SOCIETY
45 BEACON ST.
BOSTON, MA 02108

AMERICAN METEORO. SOCIETY
METEOR. & GEOASTRO. ABSTRACTS
P.O. BOX 1736
WASHINGTON, DC 20013

MR. W. G. SCHRAMM/WWW
WORLD METEOROLOGICAL
ORGANIZATION
CASE POSTALE #5, CH-1211
GENEVA, SWITZERLAND

DIRECTOR, JTWC
BOX 17
FPO SAN FRANCISCO 96630

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